

## ISLANDING OPERATION OF RENEWABLE ENERGY SOURCES IN A MICRO GRID SYSTEM

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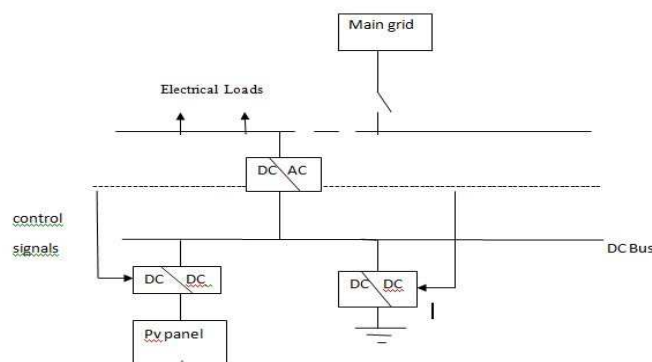
### ABSTRACT

Parallel operation of several renewable sources in a grid system is a typical problem. Each source generates at a different voltage and power. The power management of these sources with conventional topology is difficult and also complicated. This paper proposes a novel converter topology with multi DC source inputs and also with a storage element. The voltages of the sources are boosted and converted to AC using a conventional PWM inverter and interconnected to the micro grid through LC filter. The multiple input converter has three modes of operation which are explained in this paper with complete design and analysis of operation using MATLAB Simulink software.

**KEYWORDS:** Multi DC Source, PV Array, Fuel Cell, Storage Elements, Boost Converter, SVPWM Generator, Micro Grid

### INTRODUCTION

Electrical power generation through traditional methods (fossil flues) which produces large amounts of gases causing global warming has to be replaced with renewable energy power generation. Utilization of renewable source efficiently is challenge to electrical industry. From past few years there is a great advancement in renewable energy power generation with inducing power electronic devices. In near future there is a scope of increase in several power electronic renewable energy power generations with greater efficiencies. Multiple renewable sources can be used to provide reliability for the grid. Considering a micro grid where the power generated from multiple renewable source can be observed.

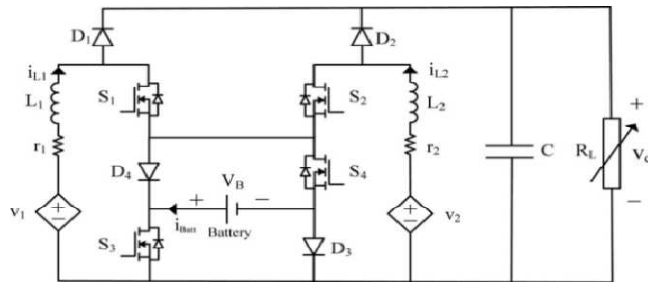


**Figure 1: Micro Grid System with Renewable Sources**

In the above figure the main grid is connected to a micro grid with PVA, PVA (solar) and storage elements with several DC-DC converters. The converters are controlled with a central control unit with power management algorithm

increasing the complexity. Each converter is independent and generates power as per the operation of the devices. PVA and wind energy sources are most promising options for the renewable power generation. However there are many other renewable sources such as Fuel cell, battery, super capacitors etc. These are considered to be a backup for the solar and wind generation systems.

## CONVERTER TOPOLOGY



**Figure 2: Schematic View of Multi-Input Converter**

In order to overcome the problems of independent power generation this paper proposes a converter topology which utilizes three renewable source inputs with four power electronic switches (MOSFETs) operating independently with independent duty ratios. By changing the duty ratios of these power electronic switches the modes of operation are explained. The three sources which are used in the simulation are

- PVA (Solar power)
- Fuel cell
- Battery (Lead Acid)

## MODES OF OPERATION

Depending upon the switching states of the four switches  $S_1$ - $S_4$  the operating mode of the converter is considered. The charging and discharging modes of the battery are defined with respect to the load conditions of the renewable sources PVA and fuel cell. Each switch has its own duty ratio ( $d_1$ - $d_4$ ) the considering  $\min(d_1, d_2) > d_3, d_4$  in battery charging or discharging mode. Let us assume the duty ratio  $d_2$  is greater than  $d_1$  for simplification of the study of operation of the converter. The switches are considered to be ideal with no conduction loss all steady state equations are generated according to the operating modes.

### First Operating Mode without Battery

In this operating mode let us consider the circuit with two sources PVA and fuel cell stack with a voltage output of 82V and the battery is disconnected. There are three operations of the switches in this mode given below At the first switching operation the switches (MOSFETs parallel to diode)  $S_1$ ,  $S_2$  and  $S_4$  are in ON state. The inductors  $L_1$  and  $L_2$  are charged with currents  $i_{L1}$  and  $i_{L2}$  avoiding the battery path. In this mode we can observe that the duty ratio of the  $S_4$  switch is 1 and the duty ratio of the  $S_3$  switch is 0 throughout the switching period. Therefore three different switching states are achieved in one switching period.

- **Switching State 1**

Let us consider the total time period is 'T' sec so the switching state 1 is between  $0 < t < d_1T$  where,  $d_1$  is the duty ratio of the first switch  $S_1$ . At time  $t=0$  the two switches  $S_1$  and  $S_2$  are switched ON for charging of the inductors  $L_1$  and  $L_2$  with the voltages of the PVA source ( $V_1$ ) and the fuel cell stack ( $V_2$ ).

- **Switching State 2**

In the second switching state which is considered between  $d_1T < t < d_2T$  The  $S_2$  switch is remained in ON state and the switch  $S_1$  is turned OFF which makes the inductor  $L_1$  to discharge through diode  $D_1$  into the load. As the switch  $S_2$  is still ON the inductor  $L_2$  is still in charging mode by the fuel cell voltage  $V_2$ .

- **Switching State 3**

In the final or third switching state time considered between  $d_2T < t < T$  the switch  $S_2$  is also turned OFF making both the switches to be in OFF state. The charge present in  $L_2$  is now discharged through diode  $D_2$  to the load. The equations of the discharge modes are given below.

$$L_1 : d_1T(v_1 - r_1 i_{L1}) + (1 - d_1)T(v_1 - r_1 i_{L1} - v_0) = \quad (1)$$

$$v_0 = \frac{v_1 - r_1 i_{L1}}{1 - d_1}$$

$$L_2 : d_2T(v_2 - r_2 i_{L2}) + (1 - d_2)T(v_2 - r_2 i_{L2} - v_0) = 0 \quad (2)$$

$$v_0 = \frac{v_2 - r_2 i_{L2}}{1 - d_2}$$

$$C: (1 - d_1)T i_{L1} + (1 - d_2)T i_{L2} = T \frac{v_0}{R_L} \quad (3)$$

$$i_{Batt} = 0 \rightarrow P_{Batt} = 0$$

## Second Operating Mode with Battery Discharging

In the second operating mode the two sources PVA and fuel cell operate with also the battery in discharging state. In this operating mode by turning ON simultaneously the switches  $S_3$  and  $S_4$  are resulting in conduction of current  $i_{L1}$  and  $i_{L2}$  through  $S_4$  and battery making the battery discharge. The discharging of the battery can be stopped when the switches  $S_1$  and  $S_2$  are turned ON which depends upon the duty ratios  $d_1$  and  $d_2$  and  $i_{L1}$  and  $i_{L2}$  currents. Therefore the power of the discharging battery can be given as

$$P_{max.batt.dis} = V_B [d_1 i_{L1} + d_2 i_{L2}] \quad (1)$$

For regulating the discharging power of the battery controlling the duty ratio  $d_3$  i.e.; by varying the switching state of any of the switches  $S_4$  or  $S_3$  before the switches  $S_1$  and  $S_2$  are turned OFF. The currents of the dependable sources change the path through the diode  $D_4$  making the battery to be discontended from the operation. The switching states of the second operating mode are explained below.

- **Switching State 1**

This switching state is between  $0 < t < d_4T$  where the switches  $S_1$ ,  $S_2$  and  $S_4$  are turned ON at time  $t=0$ sec. The two inductors  $L_1$  and  $L_2$  will be charged with voltages of the two sources PVA and fuel cell with battery i.e., the voltages  $V_1+V_b$  and  $V_2+V_b$  where  $V_b$ = battery voltage.

- **Switching State 2**

The switching state is between  $d_4T < t < d_1T$ , during this time the switches  $S_1$  and  $S_2$  are still ON but the switch  $S_4$  is turned OFF at time  $t = d_4T$ . Due to this switching operation the battery is disconnected from the circuit and the inductors  $L_1$  and  $L_2$  are charged with voltages  $V_1$  and  $V_2$  of the dependable sources.

- **Switching State 3**

This switching state is between  $d_1T < t < d_2T$  that is at time  $t = d_1T$  the inductors  $L_2$  is still charging as the switch  $S_2$  is still ON. The switch  $S_1$  is OFF so that the charge present in the inductor  $L_1$  is discharged through diode  $D_1$  into the load.

- **Switching State 4**

The switching state is between  $d_2T < t < T$  at time  $t = d_2T$  where the switch  $S_2$  is also turned OFF and the charge present in the inductor  $L_2$  is also discharged through diode  $D_2$  with inductor  $L_1$  into the load. All the discharge equations are given below.

$$L_1 : d_4T(v_1 - r_1 i_{L1} + v_B) + (d_1 - d_4)T(v_1 - r_1 i_{L1}) + (1 - d_1)T(v_1 - r_1 i_{L1} - v_0) = 0 \quad (1)$$

$$v_0 = \frac{v_1 - r_1 i_{L1} + d_4 v_B}{1 - d_1}$$

$$L_2 : d_4T(v_2 - r_2 i_{L2} + v_B) + (d_2 - d_4)T(v_2 - r_2 i_{L2}) + (1 - d_2)T(v_2 - r_2 i_{L2} - v_0) = 0 \quad (2)$$

$$v_0 = \frac{v_2 - r_2 i_{L2} + d_4 v_B}{1 - d_2}$$

$$C: (1 - d_1)T i_{L1} + (1 - d_2)T i_{L2} = T \frac{v_0}{R_L} \quad (3)$$

$$i_{Batt} = d_4(i_{L1} + i_{L2})$$

$$P_{Batt} = v_B d_4(i_{L1} + i_{L2})$$

The duty ratio  $d_4$  regulates the discharging of the battery while  $d_1$  and  $d_2$  regulates the voltage of the PVA and fuel cell sources

### Third Operating Mode with Battery Charging

The third operating mode is where the battery gets charged up with the other two dependable sources however the supply of the load is continued. The switches  $S_1$  and  $S_2$  are turned ON and the switches  $S_3$  and  $S_4$  are turned OFF. The conduction of both the currents  $i_{L1}$  and  $i_{L2}$  is done through the battery passing through  $D_3$  and  $D_4$  which charges the battery. Therefore the charging time of the battery depends upon the duty ratio of  $S_1$  and  $S_2$  i.e.,  $d_1$  and  $d_2$  and also the currents  $i_{L1}$  and  $i_{L2}$ . The power of the battery charged is given as

$$P_{\max, batt, ch} = -V_B [d_1 i_{L1} + d_2 i_{L2}]$$

The two switches  $S_3$  and  $S_4$  are controlled by changing the state of these two switches keeping  $S_1$  and  $S_2$  ON the charging of the battery can be controlled. Making the duty ratios  $d_3, d_4 < \min(d_1, d_2)$  the charging power given to the battery can be controlled. When the switch  $S_3$  is turned ON the charging of the battery is not complete. There are four switching states in this mode of operation explained below.

- **Switching State 1**

This switching time is between  $0 < t < d_3T$  where at time  $t = 0$  the switches  $S_1, S_2$  and  $S_3$  are switched ON so that the sources PVA and fuel cell charges the inductors  $L_1$  and  $L_2$  with currents  $i_{L1}$  and  $i_{L2}$  with voltages  $V_1$  and  $V_2$  respectively. Here the battery is disconnected from the system.

- **Switching State 2**

In this switching state 2 that is between  $d_3T < t < d_1T$  at time  $t = d_3T$  considering 'T' as the switching time period the  $S_1$  and  $S_2$  switches are remained ON and the  $S_3$  switch is turned OFF. This makes the battery also get charged up with both the inductors  $L_1$  and  $L_2$  by voltages  $V_1 - V_b$  and  $V_2 - V_b$ .

- **Switching State 3**

The time is considered between  $d_1T < t < d_2T$  that is at time  $t = d_1T$  sec the switch  $S_1$  is turned OFF so that the current in the inductor  $L_1$  is discharged into the load through  $D_1$ . As the switch  $S_2$  is still ON the inductor and the battery are still charged by the fuel cell source with a voltage of  $V_2 - V_b$ .

d) **Switching State 4**

In the last and fourth switching state the time laps is between  $d_2T < t < T$  all the switches  $S_1, S_2, S_3$  and  $S_4$  are turned OFF so that both the inductors  $L_1$  and  $L_2$  gets discharged into the load through diodes  $D_1$  and  $D_2$ . The discharging equations are given below

$$L_1 : d_3T(v_1 - r_1 i_{L1}) + (d_1 - d_3)T(v_1 - r_1 i_{L1} - v_B) + (1 - d_1)T(v_1 - r_1 i_{L1} - v_0) = 0 \quad (1)$$

$$v_0 = \frac{v_1 - r_1 i_{L1}(d_1 - d_3)v_B}{1 - d_1}$$

$$L_2 : d_2T(v_2 - r_2 i_{L2}) + (d_2 - d_3)T(v_2 - r_2 i_{L2} - v_B) + (1 - d_2)T(v_2 - r_2 i_{L2} - v_0) = 0 \quad (2)$$

$$v_0 = \frac{v_2 - r_2 i_{L2}(d_2 - d_3)v_B}{1 - d_2}$$

$$C: (1 - d_1)T i_{L1} + (1 - d_2)T i_{L2} = T \frac{v_0}{R_L} \quad (3)$$

$$\text{Battery: } i_{Batt} = -(d_1 - d_3)i_{L1} - (d_2 - d_3)i_{L2}$$

$$P_{Batt} = -v_B[(-d_3)(i_{L1} + i_{L2}) + d_1 i_{L1} + d_2 i_{L2}]$$

## SIMULATION AND RESULTS

Block Diagram:

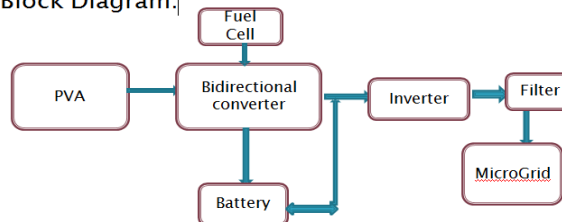


Figure 3: Novel Topology Connected to Micro Grid

As we can see in the Simulink model two renewable sources PVA and fuel cell are utilized for the power generation with a terminal voltage of 82V which are stepped up to 500V. The MOSFETs with parallel diodes are connected as per the circuit configuration with a ripple reduction capacitor at the output. The output of the novel topology is connected to a three level PWM inverter with SVPWM control generating three phase AC PWM waveforms. The three phase PWM AC output is connected to a LC filter to reduce the harmonics in the output. The reduced harmonic filtered three phase AC supply is fed to the micro grid.

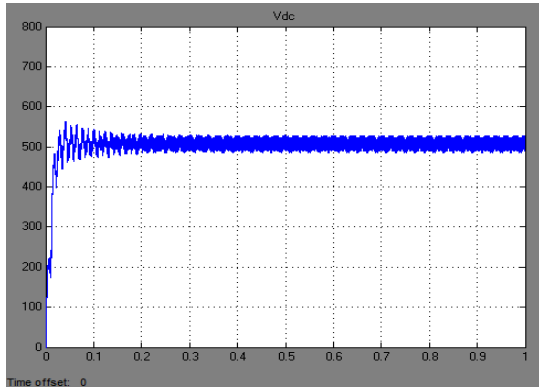


Figure 4: Output DC Voltage of the Novel Converter – Mode2

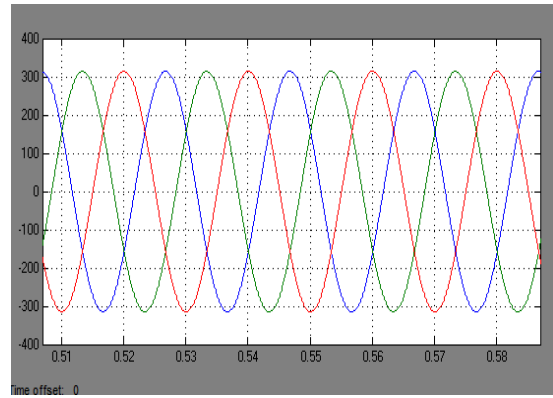


Figure 5: Three Phase Filtered Output Voltage of the Inverter-Mode2

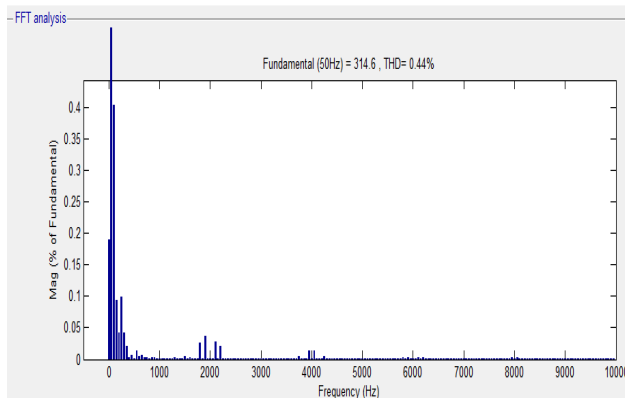


Figure 6: Total Harmonic Distortion of the Grid Connected System-Mode2

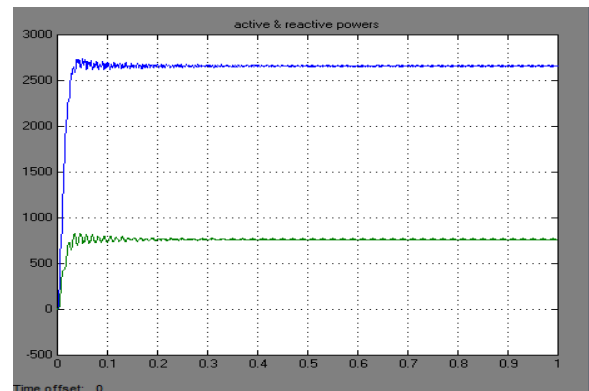


Figure 7: Active and Reactive Power of the Inverter-Mode 2

Table 1: Results for 3-Modes of Operation

Modes	Model1	Mode2	Mode3
V <sub>dc</sub> output voltage of converter	210V	500V	183V
Active power (W)	450 w	2.7KW	323W
Reactivepower (VAR)	135VAR	750VAR	95VAR
THD Values	0.57%	0.44%	0.46%

## CONCLUSIONS

In this paper we have successfully simulated a model of a hybrid power generation system with various renewable sources which can be operated stand-alone connected in parallel to each other. The output voltage has a gain of 6 times to the input of the sources which can be controlled to the required voltage and covert the DC voltage to AC and connect to the

micro grid system. In further extension to this topology, the circuit can be modified and can modeled for 'n' number of inputs also.

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